AP Physics Free Response Practice – Thermodynamics – ANSWERS

1983B4

a. Since T is constant, pBVB = p0V0 and VB = 2V0 gives pB = ½ p0

b. ΔU = Q + W, since AB is isothermal, ΔU = 0 and W = –Q = –1000 J

c. The entropy of the gas increases because ΔS = Q/T and Q is positive (heat was added)

d. In a reversible (Carnot) engine giving Qc = 400 J

e. Negative. In a clockwise cycle, the work done on the gas is negative. Or for the cycle Qnet = +600 J and ΔU = 0 so W = –Q = – 600 J

1996B7

a. p1/T1 = p2/T2 gives p2 = 0.82 atm = 8.2 × 104 Pa

b. F = p × Area = 410 N

c. Since volume and temperature are constant, we can use p1V = n1RT and p2V = n2RT. SUbtractnig the two equations gives ΔpV = ΔnRT, or Δn = ΔpV/RT = 5.45 × 10–3 mol

1986B5

a. (use absolute temperature) gives ec = 0.074

b. e = W/QH, or QH = W/e = (100 MW)/(0.074) = 1350 MW and QC = QH – W = 1250 MW (note Q may represent heat in Joules or rate in Watts)

c. AB is isothermal so ΔT = 0. It is an expansion so W is – and Q = –W  
BC is adiabatic so Q = 0. Temperature drops so ΔT is negative.  
CD is isothermal so ΔT = 0. It is a compression so W is + and Q = –W  
BC is adiabatic so Q = 0. Temperature rises so ΔT is positive.



2004B5B

a. Since PA = PB and VA/TA = VB/TB giving TB = T2 = T1/2

b. CA is an isotherm so TA = TC so PAVA = PCVC; P1V1 = P2(V1/2) giving P2 = 2P1

c. Work is the area under the line. No work is done from B to C so we just need the area under line AB. Specifically, W = –PΔV = –P1(V1/2 – V1) = +½P1V1

d. Heat was added in processes BC and CA, but not in AB.  
BC: W = 0 so ΔU = Q and temperature rises so ΔU is positive  
CA: ΔU = 0 (isotherm) so Q = –W and it is an expansion so W is negative and therefore Q is positive  
AB: Compression so W is + and temperature drops so ΔU is negative and Q = ΔU – W which must be negative

1989B4

a.

b. i. The work done on the gas is the area enclosed. Area = width × height = 2V0 × P0 = –2P0V0 (negative since it is a clockwise cycle)

ii. ΔU = 0 for any cycle

iii. since ΔU = 0, Q = –W = +2P0V0

c. For process 2, W = –PΔV = –2P0 × (3V0 – V0) = –4P0V0   
and ΔU = 3/2 nRΔT = 3/2 nR(6T0 – 2T0) = +6 nRT0 = +6P0V0  
Q = ΔU – W = +6 P0V0 – (–4P0V0) = +10P0V0

1999B7

a. Since TA = TC, PAVA = PCVC giving PC = 2 × 105 Pa

b.

c. This is a clockwise cycle so the work done on the gas is negative.

d. This is a clockwise cycle so this is a heat engine.

2001B6

a. The additional pressure comes from the weight of the added block. ΔP = F/A = mg/A = 2.04 × 103 Pa and P2 = P1 + ΔP = 1.04 × 105 Pa

b. A constant temperature, P1V1 = P2V2, or V2 = P1V1/P2 = 1.47 × 10–3 m3

c. Since the external pressure and the added weight do not change, the pressure remains constant, therefore the process from state 2 to state 3 is isobaric

d. For similar reasons as stated above, the process from state 4 to state 1 is also isobaric.

e. Comparing state 1 and state 4, which have equal pressures: V1/T1 = V4/T4, giving V4 = V1T4/T1 = 2.05 × 10–3 m3

2006B5

a. i. P1 = P2 so V1/T1 = V2/T2 giving T2 = 746 K

ii. V1 = V3 so P1/T1 = P3/T3 giving T3 = 560 K

b. The net work done is the area enclosed by the triangle = ½ base × height = +6250 J (positive since the cycle is counterclockwise)

c. Since the cycle is counterclockwise, the work done on the gas is positive (more area under the process 2⇨3 in which positive work is done than in process 1⇨2 where negative work is done). In any cycle ΔU = 0 so we have Q = –W, therefore Q is negative meaning heat is removed.

2003B5

a. Ua – Uc = ΔUca = Qca + Wca = 685 J + (–120 J) = 565 J

b. i/ii. Heat is removed. ΔUabc = –ΔUca = –565 J since it is the opposite beginning and end points, the path doesn’t matter. Q = ΔU – W = –565 J – 75 J = –640 J

c. Wcda = Wcd + Wda = 0 + –PΔVda = –150 J

d. Heat is added. ΔU = +565 J and W = –150 J and Q = ΔU – W

2003B5B

a. pV = nRT so T = pV/nR = (200 Pa)(20 m3)/(1 mol)(8.32 J/(mol-K)) = 481 K

b. The net work done is the area enclosed by the triangle = ½ base × height = +4000 J (positive since the cycle is counterclockwise)

c. i/ii. Heat is removed. In one cycle ΔU = 0 so Q = –W = –4000 J

d. In a cyclic process ΔU = 0 (the temperature returns to the same value)

e. The entropy is a function of the state of the gas, and after one complete cycle the gas has returned to its original state so the entropy is the same.

2004B5

a. i. W = –PΔV = –3600 J. The work done *by* the gas is the negative of the work done *on* the gas, +3600 J

ii. ΔU = 3/2 nRΔT and the temperatures can be found from PV = nRT giving TA = 108 K and TB = 325 K so ΔU = 5400 J

 iii. ΔU = Q + W so Q = ΔU – W = +9000 J (remember, the W in this equation is the work done *on* the gas)

b.



c.

ii. Heat is removed. In an isothermal process, ΔU = 0 so Q = –W and in a compression W is positive.

2008B5

a.

b. ⇨Since process AB is isochoric, ΔV = 0 therefore W = –PΔV = 0 (also, there is no area under the line)  
⇨At constant volume for a fixed number of moles, pressure is directly related to temperature and since the pressure increases, so does the temperature. ΔU is directly related to ΔT so it is positive.  
⇨Q = ΔU – W and W = 0

c. Since TB = TC, PBVB = PCVC so VC = PBVB/PC = 0.005 m3

2005B6

a. The volume of the cylinder = Area × height = AH. PV = nRT then becomes PAH = nRT so H = nRT/PA

b.

c. Calculating the slope of the line above and setting it equal to the slope from the equation of part a: nR/PA gives n = 1.11 moles

2005B6B

a. PV = nRT or P = (1/V)nRT

b. The total pressure is the atmospheric pressure plus the pressure due to the added mass P = Patm + mg/A



c.

d. From P = (1/V)nRT, the slope of the above line = nRT. Slope = 6.19 Pa-m3 so n = .0025 moles

2006B5B

a. i. TA = TB so PAVA = PBVB: PB/PA = ½

ii. PB = PC so PC/PA = PB/PA = ½

iii. A and B are on the same isotherm so TB/TA = 1

iv. VC = VA so PC/PA = TC/TA = ½

b. Internal energy depends only on the temperature. Since step I is isothermal there is no change in temperature and thus no change in internal energy

c. W = –P ΔV. In step III there is no change in volume, and thus no work done.

2007B5

a. P = F/A so F = PA = P(πR2) = (4.0 × 105 Pa)π(½ 0.20 m)2 = 1.3 × 104 N

b. PV = nRT gives V = 1.2 × 10–2 m3

c. Won the gas = –PΔV so Wby the gas = +PΔV where ΔV = Ax = πR2x and x = extra distance pushed by the piston giving Wby = 1.9 × 103 J

d. Heat is transferred to the gas. This is an expansion so Won is negative. For the gas to expand at constant pressure, the temperature must also increase so ΔU is positive. Q = ΔU – W.

2007B5B

a. i. For the piston to be in equilibrium, the gas must hold it up against its own weight and the external force due to the outside pressure: F = PatmA + Mg where A = πR2 = π(D/2)2 = πD2/4 so we have F = ¼PatmπD2 + Mg

ii. P = F/A = F from above ÷ ¼πD2 giving Pabs = Patm + 4Mg/πD2

b. Pressure goes up. If heat is added at constant volume, the temperature goes up and so must the pressure since P ∝ T at constant volume.

c. W = Fx (from mechanics) = (¼PatmπD2 + Mg)x0

2008B6B

a. V1 = V2 so P1/T1 = P2/T2 giving T2 = 1500 K; P1 = P3 so V1/T1 = V3/T3 giving T3 = 1800 K

b/c. The net work done is the area enclosed by the triangle = ½ base × height = –100 J (negative since clockwise)

d. For process 1⇨2 W = 0 so Q = ΔU = 3/2 nRΔT = (1.5)(0.004 mol)(8.31 J/mol-K)(1500 K – 300 K) = 60 J

2009B4

a. PV = nRT so T = PV/nR and the number of moles = (2.2 × 103 g of H2O)/(18 g/mole) = 122.2 moles. This gives T = (3 × 105 Pa)(2 m3)/(122.2 moles)(8.31 J/mol-K) = 591 K

b. The temperature is proportional to the product of P and V. (PV)A = 6 × 105 J and (PV)C = 10 × 105 J so TC/TA = 10/6 giving TC = 985 K

c. Since the temperature increases for process A⇨B⇨C and U is dependent on the temperature, U increases.

d. WABC = WAB + WBC = 0 + –PΔV = –(4 × 105 Pa)(2.5 m3 – 2 m3) = –2 × 105 J

1974B6

a. PAVA/TA = PBVB/TB; (1.5 atm)(1 L)/TA = (0.5 atm)(3 L)/TB giving TA = TB

b. Since TA = TB, ΔUAB = 0. W is the area under the line = –2 L-atm (negative for an expansion) and we have Q = ΔU – W = +2 L-atm = +202.6 J

c. PV/T is constant so highest temperature is at the highest value of PV where P = 1 atm and V = 2 L. PV = nRT gives T = 243 K

1975B3

a. The work done on the gas is the area enclosed by the cycle = length×width = –4p0V0 (negative since clockwise)

b. In the cycle ΔU = 0 so Q = –W = +4p0V0

c. Temperature is the same where the product p × V is the same: A = p0V0; B = 3p0V0; C = 9p0V0; D = 3p0V0;   
TB = TD

d. AB: Q = ΔU – W = 3/2 nRΔT – 0 and ΔT = 2T0 ; so Q = +3nRT0 = +3p0V0  
BC: Q = ΔU – W = 3/2 nRΔT – (–pΔV) and ΔT = 6T0; so Q = 9p0V0 – (–6p0V0) = +15p0V0  
QBC > QAB

1979B5

a. Process II is isothermal. An isothermal process is one in which the temperature is constant. Thus, from the ideal gas law, the product of pressure and volume is a constant. This condition is satisfied by process II.

b. Process III is adiabatic. In an adiabatic process, both the pressure and the volume must change. Thus, processes I and IV are eliminated. Since process II is isothermal, process III is the only possible adiabatic one.

c. The gas does work in processes I, II and III. Work is done by the gas whenever the volume increases. (negative work is done by the gas when the volume decreases as well)

d. In process IV, no work is done. Since the pressure decreases at constant volume, the temperature also decreases, giving ΔU is negative and with W = 0, ΔU = Q and therefore Q is negative. One could also use the adiabatic process as the dividing line between process in which heat is added and those for which heat is removed. On the adiabatic line, Q = 0. For any process from the same initial point that lies above the adiabat, heat is added and for any process that lies below the adiabat, heat is removed.

e. RMS speed is proportional to the kinetic energy which, in turn, is proportional to the temperature. Only in process I does the temperature increase.

1991B3

a. Power is the rate of useful work form an engine so W (which here represents the rate in MW) = 120 MW and e = W/QH = 0.40 = 120 MW/QH giving QH = 300 MW

b. The rate of heat input from the combustion of oil is 300 Joules per second. Since oil provides 4.4 × 107 joules per kilogram burned we can divide to find the number of kg per second that must be combusted:   
Δm/Δt = (300 × 106 J/s) ÷ (4.4 × 107 J/kg) = 6.82 kg/s

c. QC = QH – W = 180 MW

1993B5

a. Since Pa = Pb, Va/Ta = Vb/Tb giving Tb = 750 K

b/c. ΔUab = 3/2 nRΔT = (1.5)(1 mole)(8.32 J/mol-K)(750 K – 250 K) = 6240 J  
Wab = –PΔV = –(1.2 × 105 Pa)(51 × 10–3 m3 – 17 × 10–3 m3) = –4080 J  
Q = ΔU – W = 10,320 J

d. W = –PΔV = 0 (no area under the line)

e. In a cycle ΔU = 0 so W = –Q = –1800 J

f. = 0.66

1995B5

a. P = Fv (from mechanics) = mgv = (10 kg)(10 m/s2)(4 m/s) = 400 W

b. = 0.4 or 40%

c. i. With an efficiency of 0.4 and useful work done at the rate of 400 W we have e = (W/t)/(QH/t) or (QH/t) = 1000 W

ii. (QC/t) = QH/t) – (W/t) = 600 W